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Energy Efficiency in Mobile Cloud Computing: A Survey

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Abstract: The advancement of cloud computing and spontaneous development of mobile applications forms the basis for Mobile Cloud Computing (MCC) as an emerging technology for mobile services. Even with the massive usage of mobile computing, utilizing it potentially is a challenge due to frequent disconnections, security, mobility and resource scarcity such as battery life, storage and bandwidth. The major limitations for MCC are bandwidth and energy. This study gives a survey of mobile cloud computing research with energy efficiency and also picturize an overview of various cost models including the scheme of classification based on the major issues and describes various approaches to overcome these issues. Energy-cost constructs usually form a tradeoff in mobile cloud computing scenario. The offloading methods and the analysis of mobile-cloudlet-cloud experiment with the results are presented in this study. This study gives significant challenges in mobile cloud computing that are not yet fully solved and emphasizes on the future direction of research.

Key words: Mobile cloud computing, energy efficiency, offloading, cloudlet, survey

INTRODUCTION

The study by Smart Insights Research states that as on June 2015, 80% of internet users own a smartphone and nearly 1900 million people are global mobile users. The study by Flurry Analytics, says mobile users grow 76% year over year. This shows the demand for mobile computing. However, with mobility comes their intrinsic problem such as limited energy, low connectivity and resource scarcity (Satyanarayanan, 1996). The users encounter a severe impact in mobile device usage due to its limited battery power. To overcome this problem cloud computing can be integrated with mobile computing as MCC.

Cloud computing vs MCC

Cloud computing: cloud computing provides software as a Service as on-demand service without a datacenter. Various services are available over the Internet using virtualized resources in cloud computing

Mobile Cloud Computing (MCC): In Fig. 1, the MCC architecture reveals that offloading from Mobile environment to cloud environment via the Internet is viable. The different concepts of 'mobile cloud' are.

Centralized cloud: In general, MCC is termed as using a remote server; an application from a thin client can be executed. Here the thin client is the mobile device connected to the resourceful remote server (Fernando *et al*., 2013). The MCC application uses the Cloud for data processing and storage (Mobile cloud computing forum).

Cloudlets: Another MCC approach is cloudlet concept. Here the mobile devices offload its application to a local surrogate server called Cloudlet. The Cloudlet consists a number of multicore computers connected to the remote cloud servers (Satyanarayanan *et al*., 2009).

Distributed mobile cloud: In this approach the nearby mobile devices through peer to peer network act as a cloud resource providers (Marinelli, 2009). The cloud computing and mobile cloud computing comparison based on the issues is given in Table 1.

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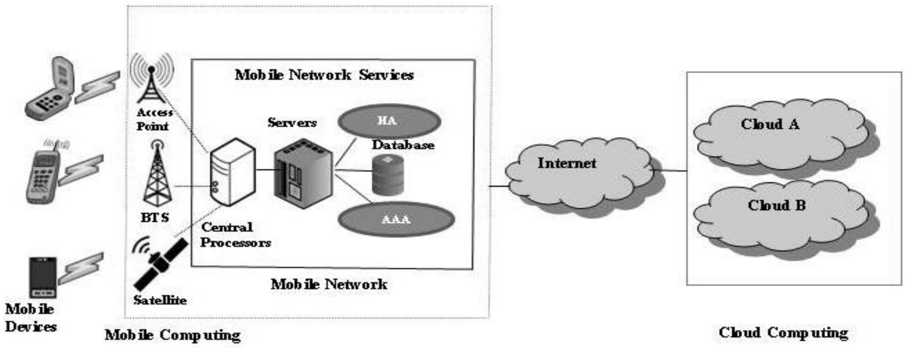

Fig. 1: Mobile cloud computing architecture

Table 1: Comparison of CC and MCC based on Issues

Issues	Cloud computing	Mobile cloud computing
Bandwidth utilisation cost	No	Yes
Network connectivity	No	Yes
Device energy	No	Yes
Mobility	No	Yes
Location awareness	No	Yes
Context awareness	No	Yes
Bandwidth	No	Yes
Security	Yes	Yes

Energy consumption and MCC: To overcome the resource scarcity of mobile devices, various researches are done in mobile computing to optimize the energy consumption of these devices. The study of energy usage in MCC is termed as green mobile cloud. As the cloud computing uses fixed power source, the researchers focus on the cloud computing in energy consumption for mobile computing. At present, various strategies follows up for the enhancement of mobile device energy via offloading its work to cloud computing environment. The researchers in Kumar and Lu (2010) suggest that by offloading the right context, the mobile device energy can be optimized. However, this is suitable only for certain applications.

Jung *et al*. (2011) the researchers proposed to deploy a client proxy at mobile devices in cloud computing environment and thereby the energy consumption is reduced in the mobile device. The tokens are used for the complete interactions. An energy profiling technique is presented by Moreno *et al*. (2011) to reduce the energy consumption in wireless networks. To increase the energy profiling to network design with energy aware systems, the network-wide information is considered. By this technique, the designers examine various designs and take decisions to optimize their designs based on the energy.

The processing power is scaled based on the data rate at the router, to attain the rate adjustment in the green routers. Hence, the clock frequency of the router processes can be customized based on the input data rate and is presented by Lombardo *et al*. (2012). The analysis is made to study the feasibility of multimedia cloud computing to provide EaaS (Energy as a Service) in (Altamimi *et al*., 2012) . The result proves that the mobile device energy can be saved from 30-70% when multimedia cloud computing provides the multimedia functionalities to the mobile device. Zhang *et al*. (2013, 2015) the authors proves that using stochastic wireless channel, the energy optimization is possible by offloading mobile services to the cloud.

Energy Efficient Code Generator for Mobile phones (ECGM) was introduced by Fekete *et al*. (2013a, b). During compile time, this system automatically decides which task can be offloaded and which task can be run on a mobile device. The scheduling techniques are used to measure the benefits of the system.

To forecast the user demand in video playback a Gaussian Mixture Model (GMM) is constructed through user behavior analysis. During the playback process, video downloading strategy which is energy efficient will be determined gradually. Results are compared with a static downloading strategy that is optimized by an exhaustive tail. The proposed method in (Shen and Qiu, 2013) proves that in average 10% of the wasted energy can be reduced.

The (Ickin *et al*., 2013) proposed ExpCO2 is used to save energy. The result shows that, by restrictive network traffic and increasing the resource efficiency of services, the total energy utilization can be reduced. Based on the scheduling theory the offloading was done. The measurements were made in various scenarios but focused on energy saving through offloading tasks. This measurement system which is used to check the energy consumption of the mobile devices is presented in (Fekete *et al*., 2013a, b). A vendor-agnostic method and a power model are developed by the researchers in (Vishwanath *et al*., 2014) that permits to measure the Internet equipment energy efficiency. This technique verifies the efficiency by using different types of switches and routers. From a group of mobile devices, the Femtocloud system (Habak *et al*., 2015) imparts a self-configuring, dynamic mobile cloud. This architecture enables various mobile devices to work together as a cloud computing service.

Energy is considered as a significant factor. The ultimate aim of MCC is to improve the resource efficiency often by offloading the mobile device work to cloud environment. Hence, this section describes the need for energy efficiency in mobile cloud.

Energy issues in MCC: The various issues related to energy in mobile devices when offloading is done in the cloud are:

- Energy characteristics of mobile device; ideal device consumes less power. When radio interface starts communication, the device consumes the power 5 times as high as an ideal device.
- Communication overhead; interface doesn't turn on and off instantaneously even after the communication ends.
- Poor signal condition; poor signal consumes more energy
- Processor clock speed; when processor clock speed doubles, the power consumption nearly octuples (Kumar and Lu, 2010)

MATERIALS AND METHODS

Energy consumption reduction techniques: The energy consumption reduction techniques available are:

- Offloading method; the distributed server is used to execute the mobile device computation. For further energy saving, pointers are used for sending data (Smelcerz, 2013)
- DVFS (Dynamic Voltage and Frequency Scaling); additional hardware circuit is needed to implement this method in cloud systems to control the power consumption of each node. Kolodziej (2012) authors implemented this method by changing the clock speed

Offloading methods: OS-Level Offloading: It is a self-managed datacenter in a box. The Virtual Machines operating system can be fully controlled. This kind of offloading is done in Cloudlet (Satyanarayanan *et al*., 2009). Manually partitioning the program and more initialization overhead are the main issues in Cloudlet.

Thread-level offloading: Distributed execution without manually modifying the source code. In CloneCloud (Chun *et al*., 2011) architecture undergoes this offloading. The overhead is more for complex applications and the security issues are not to be considered as major issues in this framework.

Method-level offloading: If only the remote execution saves energy, the method is offloaded to the remote server. MAUI (Cuervo *et al*., 2010) is a kind of this offloading.

Cost models IN MCC: Existing cost models of the current MCC systems falls into three categories: performance Enhancement model, energy enhancement model, Hybrid Application model. An overview is given in Table 2. It shows the comparative study of various MCC offloading frameworks and shows that MCC provides best optimal solution cost model in terms of execution time and energy. MAUI (Cuervo *et al*., 2010) maximizes the energy savings by fine-grained code offload. It also minimizes the burden on the programmer. Latency and network bandwidth are considered to integrate the cost. This profiler considers the issues of energy in mobile device. The profiler data is fed into the solver and the solver decides to execute the method in mobile device or remote server. The result shows that it gives best partitioning strategy for the battery usage of the mobile device. Cuckoo (Kemp *et al*., 2012) is an android platform focused programming model. It merges with the Eclipse tool and Android framework that allows local and remote implementation with single interface. The decision parameters are decided at runtime.

In μCloud (March *et al*., 2011), a mobile application is considered as a collection of different types

Table 2: Overview of MCC Cost Models

Cost Model	Execution time&energy Consumption	Band width	Security	Latency	Model category	Offloading framework	Offloading decisions
MAUI	Low	Low	Low	Low	Energy	Method level	Dynamic
Cuckoo	Low	Low	Low	Medium	Hybrid	Programming Model	Dynamic
iCloud	Low	Low	Low	Low	Energy	Mash Up Approach	Static
Clonecloud	Low	High	Low	Low	Performance	Thread Level	Dynamic
Think Air	Low	Low	Low	Low	Hybrid	Method Level	Dynamic
mCloud	Low	Low	Low	Low	Hybrid	Context Aware Method Level	Dynamic

of components. It follows dynamic offloading table as components, dispersed to cloud and mobile devices to model rich mobile parameters which are decided at run time. A ‘Dynamic Profiler’ is used to collect data usage through cost-benefit analysis in CloneCloud (Chun *et al*., 2011). In order to minimize the cost of migration and execution time, the optimization solver is used to find the migration methods. The costs refer to energy consumption, execution time or resource footprint.

An android emulator that allows executing mobile applications on x86 architecture machines is used in ThinkAir (Kosta *et al*., 2012). Code offloading decisions are made based on the energy consumption, execution time or both. The data transfer cost and network speed are not taken into account is considered as a major issue in this model. Cloud (Zhou *et al*., 1939) is a Code offloading framework which consists of mobile devices, cloud services and nearby cloudlets to enhance the performance of the MCC services. The code offloading decisions were made at runtime by choosing the wireless channel and cloud resource. A context-aware algorithm is proposed for offloading decisions.

Emerging applications in MCC: The limitation of battery in mobile devices makes the data processing as expensive. The recent developments in technology enhance the mobile devices with good resolution camera, barometer, memory etc., The future MCC application uses the sensing ability of mobile devices for the collection of data. The offloaded data to the cloud merge with mobile device observations and data analytics methods and are used to extract the embedded patterns. The data can be gathered from billions of mobile devices at runtime. With the potential processing power and unlimited storage, MCC brings out significant applications. Using the offloading methods like cloudlet, it is able to accelerate both Bigdata access and collection which will be helpful in internet of things. The emerging MCC applications are listed below:

- Crowd sourcing (Yang *et al*., 2012, 2015; Hosseini *et al*., 2014; Guerriero *et al*., 2015)
- Collective sensing (Lane *et al*., 2010; Cheng *et al*., 2010; Roy *et al*., 2015)
- Traffic/Environment monitoring (Yang *et al*., 2015, 2012; Kanagaraj *et al*., 2015; Ray *et al*., 2015; Hunter *et al*., 2011)
- Mobile cloud social networking (Wang *et al*., 2013; Khalid *et al*., 2014; Zhu *et al*., 2014)
- Mobile cloud healthcare (Wu *et al*., 2013; Cimler *et al*., 2014; Jemal *et al*., 2015)
- Location-based mobile cloud service (Sekar and Liu, 2014; Kliazovich *et al*., 2012)
- Augmented reality and mobile gaming (Kim *et al*., 2014; Ambikadevi *et al*., 2014, Cordeiro *et al*., 2015)

RESULTS AND DISCUSSION

Experiment design: To analysis, the power consumption of mobile device based on offloading, three environments, mobile device, mobile-cloud and mobile-cloudlet-cloud are considered for application execution. The mobile device used for this experiment is HTC One_M8 Eye with Android 6.0.1 Operating System. The cloudlet is a Laptop with Windows 8.1 operating system. The physical communication channel is made between the mobile device and Laptop via WiFi. A Wireless Access Point (WAP) is setup with the Laptop through which the mobile device can communicate. The Laptop establishes the connection to the cloud via WiFi. Through Virtual Network Computing (VNC) which uses the Remote Frame Buffer Protocol, the mobile-cloudlet-cloud communication is esablished. For mobile to direct cloud communication the mobile device uses WiFi Internet.

The power consumption of mobile device is calculated, for the following running applications, 5 minutes for video stream, 20 moves for chess game and scientific calculator with 10 trigonometric equations are measured using Power Tutor application. To test three different environments, firstly, the mobile device is connected to the cloud via WiFi Internet runs the application using the cloud resources. Secondly, the mobile device is connected with cloud via cloudlet uses the access point to run the application. Finally, the

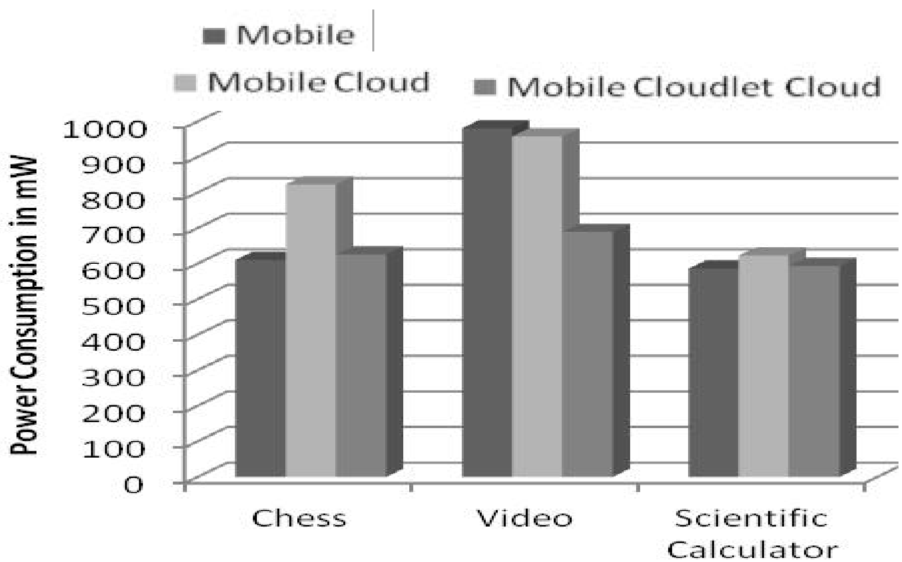

Fig. 2: Analysis of power consumption by the applications on the mobile device

Table 3: Average power consumption of the applications on the mobile device since the profiler started

Applications	Mobile device (mW)	Mobile-Cloud (mW)	Mobile-Cloudlet Cloud (mW)
Chess	610	823	626
Video stream	981	958	689
Scientific calculator	586	623	593

applications are downloaded on the mobile device and it uses the mobile device resources to run. Table 3 shows the average power consumption of the applications on the mobile device.

The results analyzed in bar chart in Fig. 2 shows that video stream application consumes 40% more power on mobile device enviroment and 30% more power on mobile cloud environment compared to other two applications. But in the mobile-cloudlet-cloud environment the power consumption of video stream application is 10% higher than other two applications. Even though the mobile device environment consumes 5% lesser power than mobile-cloudlet-cloud environment in chess and scientific calculator applications, it consumes more device storage. This shows that mobile-cloudlet-cloud environment has better offloading solution for energy efficiency with mobile device.

CONCLUSION

MCC is an emerging field which provides huge performance in mobile device by using energy optimization techniques. As of today, the available MCC solutions do not overcome all the mobile computing limitations. The various study shows, using MCC will prove to be optimistic energy solution than the opportunistic model. The MCC general model is presented in this work. Further MCC is compared with Cloud Computing based on the issues. This study primarily discusses the MCC energy issues and available techniques to reduce the energy consumption. The offloading techniques are considered as hopeful techniques to overcome the energy issues of mobile devices. The different types of offloading techniques, existing cost models and emerging applications are discussed in this work. Also, an experiment is conducted to analyze the power consumption of mobile device in offloading mobile-cloudlet-cloud environment. The results show that the mobile-cloudlet-cloud environment consumes less energy than mobile-cloud environment in all the three applications assuming good cost impact. Much other similar works are available but the purpose of this work is to provide an overview of MCC potential and the need for energy efficiency in mobile cloud. The native mobile applications are not flexible to integrate with cloud compute. Similarly, web applications are not flexible to integrate with mobile device. Hence, the potential of MCC can be enhanced by dynamically shifting applications between mobile device and cloud. Many researchers prove that by offloading to remote server or nearby device or nearby computers the battery power of mobile device shall be enhanced. MCC has challenging research problems; to solve these problems it requires interdisciplinary research from networks, hardware and human-computer interaction perspectives. As seen, the energy efficiency problem in mobile cloud is critical. Until now, the optimal solutions are not available for energy issues in MCC which makes the research area wide open.

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